Results of the Olmsted Hydraulic Operated Wicket Dam

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Background

Olmsted Locks and Dam is one of the largest civil works projects undertaken by the Corps of Engineers to lead the modernization of Corps navigational facilities for the twenty-first century. The project is being constructed on the Ohio River, 16 miles (25.7 kilometers) upstream from the confluence of the Ohio and the Mississippi Rivers near the community of Olmsted, IL. The project has undergone numerous conceptual changes throughout its development. The present design consists of construction of two 110 foot (33.53 meters) wide by 1,200 foot (365.76 meters) long lock chambers with five 110 foot (33.53 meters) wide hydraulically operated tainter gates and 1,400 feet (426.72 meters) of navigable pass dam. Construction of the Olmsted Locks and Dam Project was authorized by the United States Congress on 17 November 1988 by the passage of the Water Resources Development Act of 1988. The cost of this project is being equally shared with the navigation industry. Tariffs paid by the navigational industry on diesel fuel are used to form an Inland Waterways Trust Fund which will provide 50 percent of the project cost. Current estimated total project cost is over $1 billion U.S. dollars.

Aerial view of Prototype

The Olmsted Dam was originally projected to include 2,200 feet (670.56 meters)of navigable pass with 220 hydraulic operated wicket gates. In late 1995 a decision was made to change the design of the navigable pass dam from a full width hydraulically operated wicket dam to a combination of boat operated wickets and tainter gates. Prior to this decision, a prototype test facility of the hydraulic operated wicket dam was under construction at Smithland Lock and Dam on the Ohio River. The Corps of Engineers completed construction and tested the hydraulic operated wicket dam at Smithland to learn more about the modern design and evaluate materials used at the site.

The Olmsted Prototype hydraulic operated wicket dam was constructed on the Kentucky bank of the Ohio River. A 1,100 foot (335.28 meter) long, 250 foot (7.62 meter) wide approach channel and 600 foot (182.88 meter) long retreat channel was dug to bring the Ohio River to and from the site. Construction began in May of 1994 and was completed in December 1995 at a cost of $18 million U.S. dollars.

Testing of the wickets and components began on 4 December 1995 and lasted till 12 August 1996. At that time the entire site was dewatered and the wickets and components were disassembled for inspection. Many lessons were learned both during construction and during testing of the design. Each wicket and its related hydraulic operator was raised and lowered under various heads from 1 to 20 feet (.3 to 6.09 meters). The wickets were operated for 25 cycles each and then left stationary in the raised position. This operation continued until 400 cycles of movement of each gate had been achieved. Each piston rod was extended when not in use to expose it to the same amount of debris and wear.

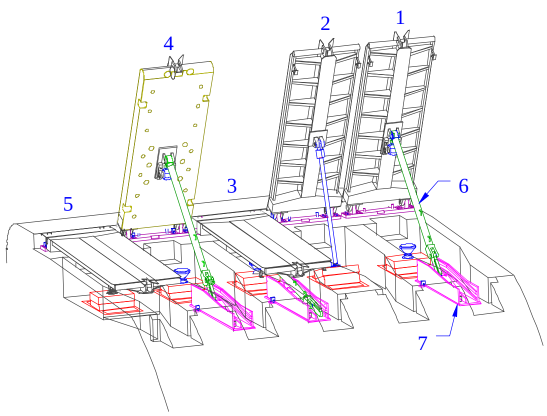


Figure 1, View of components

1. Steel wicket, retractable cylinder, ceramic coated piston rod.
2. Steel wicket, direct connected cylinder stainless steel with chrome coated piston rod.
3. Steel wicket, retractable cylinder, Ceramax coated piston rod.
4. Composite wicket, retractable cylinder, two layers chrome coated piston rod.
5. Steel wicket, direct connected cylinder, one layer chrome over one layer nickel coated piston rod.
6. Steel Prop
7. Stainless Steel hurter

Five hydraulically operated wicket gates were built and tested. A wicket is a flat gate which is hinged at its base and can be raised to a set angle to hold back flow in a river to create a dam. At 9'-2" (2.79 meters) wide, 25'-6" (7.77 meters) long, and with a design lift of 22-feet (6.7 meters), the wickets were the largest hydraulically operated in the world. Many different materials and components were designed and tested at the project. Two different types of hydraulic lifting systems were developed. Three of the wickets using a retractable piston rod with a prop were used to hold the gate in the raised position. The other two wickets used a direct connected cylinder to the gate. Rexroth Corporation, Bethlehem, PA, USA, designed and built the hydraulic power unit and used an Allen Bradley programmable logic controller to operate the system. The programmable logic controller and the personal computer were located in a control tower next to the site, above water level, but the hydraulic power unit with all valves and controls were located in a dry ten foot diameter gallery under the wickets. All the components worked extremely well despite being located in a gallery under the dam. Each cylinder was placed under the wickets and had a bore of 14 inches (355.6mm) with average stroke of 12'-3 (3.73 meters). The system had a maximum operating pressure of 3,000 psi (206.8 bar).

Cylinder suppliers were:
Victor Fluid Power, USA
Hunger Cylinders, Germany
Hydraudyne Cylinder, Netherlands
Air-Dro Cylinders, USA
Remco Cylinders, USA

The following is an account of the many lessons learned with the hydraulic system, cylinders, composite gate, paint coatings and self-lubricating bearings at the Olmsted Prototype Project.

Inside of Gallery

1. Damaged Piston Rod
One of the wickets malfunctioned during the testing phase, causing the hydraulic piston rod on the lifting cylinder to be bent. The cause of the malfunction was the jamming of a prop which caused a chain reaction of events to occur. The wicket was being operated with high tail water, which meant the hydraulic cylinder was not visible. The cylinder was retracting, lowering the wicket, and when the prop jammed the cup and ball connection between the piston rod and wicket separated. This caused the wicket to jam in the raised position causing a small alignment cylinder piston rod to break and eventually side loading on the large piston rod caused the rod to bend. The diameter of the piston rod was 7.5 inches (190mm) and was made of HR4140 alloy steel (100,000 yield) with a .022 inch (.56mm) thick ceramic coating. The photos show the aftermath of the bent rod.

Bent Piston Rod

Lessons learned from the damage were: First, to prevent this from occurring in the future, provide as much clearance as possible with large moving parts. Second, despite tremendous bending loads on the piston rod the ceramic coating was only damaged at the extreme bend in the rod. Cracks in the coating were observed along the tension side of the rod. The piston rod bent to a radius of approximately 5 feet (1.52 meters) and the coating flaked off along the bend. The rest of the rod was still in good condition. Third, the damage to the cylinders were in no way related to the manufacturing or design of the cylinders but are an important lesson learned on the durability of the ceramic coating and the catastrophic events which can occur to a piston rod.

2. Manufacturing Problems of Cylinders

One of the hydraulic cylinder manufacturers designed the trunnion of the cylinder too thin and did not allow the trunnion to be slow cooled after it was welded to the body of the cylinder. Thus, a crack developed in the steel. This caused the trunnion to be scrapped and a second trunnion made, This time the cylinder was inserted in an oven and slow cooled to prevent cracking. This caused a delay in the delivery time of the cylinder.

3. Poor Quality Cylinder Design Piston Rod Measuring Devices.

Another example of poor design and planning was, one of the cylinder manufacturers installed a Tempasonic piston rod, measuring device and damaged it at the factory. The Tempasonic device uses a long thin rod which is inserted

Base of Bent Rod

from the end of the cylinder and passed through a hole machined in the piston rod. As the piston rod extends, a signal is sent from the unit to the end of the piston rod, thus measuring its stroke. A problem developed at the factory with the rod when the cylinder was laying in a horizontal position. The piston rod was extended and the long thin Tempasonic rod bowed from its own weight inside the cylinder. As the piston rod retracted, the Tempasonic rod was crushed inside the cylinder. The manufacturer of the cylinder had never built a cylinder of this size and did not know the limits of the Tempasonic device. After replacing the unit, the cylinder was shipped to the site, where it was discovered that the unit was internally wired wrong. Because of these problems, the cylinder was removed from the site and a spare cylinder from another manufacturer was used in its place.

4. Piston Rod Seals

Two of the cylinder manufacturers, Rexroth Hydraudyne. and Hunger Cylinders, took special care in designing an O-ring seal to protect the threads on the end of the piston rods from water and debris getting into the threads. The other manufacturers did not and corrosion was extreme on the exposed carbon steel threads. The photo shows a typical unprotected piston rod after just seven months of exposure.

Corroded Threads on Piston Rod

5. Hydraulic Fluid

The Olmsted Prototype hydraulic system was installed with Mobil EAL 224H biodegradable hydraulic fluid per the Corps of Engineers specifications. Rexroth Corporation designed the hydraulic power unit with two 10 micron filters, one mounted in the supply line after the pump and one in the main return line from the cylinders. The manufacturer's data charts indicated the viscosity of the fluid to be good to 32° Fahrenheit. At the Prototype site the cylinders and hydraulic power unit were installed and operated in the dry. When the air temperature was in the range of 45°F, (7.2°C) or less, the initial operation of a cylinder caused an alarm to activate indicating a clogged return filter. The control system was designed to indicate when a pressure build-up was occurring at a filter indicating the filter was dirty and needed replacing. It was determined that the cold temperature was causing the fluid to thicken greater than was expected by the charts provided by fluid manufacturer. A decision was made to replace the 10 micron filter in the return line with a 20 micron filter and activate the reservoir heater to heat the fluid before it passes through the 10 micron filter on the supply side of the system. This modification solved the problem of the cold temperature fluid setting off the alarm of a clogged fluid filter.

6. Hydraulic Pump Wear

The hydraulic pump used to operate the system was a Rexroth Corporation, pressure compensated variable volume piston pump, capable of 8 G.P.M., (30.3 Liter/min) @ 3,000 psi, (206.8 bar) to 32 G.P.M., (121.1 Liter/min) @ 500 psi, (34.5 bar) with horse power control. A 20 horsepower, 1,750 rpm, 208, 3-phase motor was used to power the pump.

After the testing at the site was completed, inspection of the hydraulic pump was performed by removal of the pump and sending it to Rexroth Corporation. The Rexroth Corporation performed a flow test and disassembly of the pump for inspection. The results of the test indicated the biodegradable fluid has little to no effect on the pump and all components were in good working order.

7. Remote Control of Wickets

A specially designed remote control device was developed to plug into the HPU unit in the gallery. This rigid device could be used by a maintenance worker to operate any of the wickets from inside the gallery. A digital read out of piston rod position or cylinder pressure was displayed on the unit. Lessons learned from the remote operator will be used on the final Locks & Dam at Olmsted.

8. Composite Wicket

Remote Control Devise

A composite wicket was built and tested at the site. The wicket was designed by McDonnell Douglas Aerospace and constricted of a metallized steel inner frame with Morrison Molded Fiberglass (MMFG) Extren 625 glass/vinyl ester pultruded in (.75 inch (19mm) thick) sheets. The sheets were used for the upstream and downstream skin plates. In addition cross member stiffeners were fabricated from this material. The wicket and material performed beyond expectations.

The U.S. Army Construction Engineering Research Laboratories performed an evaluation of the wicket after its testing and found it to be a viable option for future uses on navigation facilities.

9. Paint Coatings

Paint evaluation was performed by U.S. Army Construction Engineering Research Laboratories. The standard Corps of Engineers paint and thermal spray coatings systems and proprietary foul-release and antifouling paints were exposed for approximately 6-months prior to inspection. Table 1 lists and describes the paint systems applied to the six steel prototype gates.

Table 1. Paint System

Wicket Position	Paint System	Description	Guide Spec.	Dry Film Thickness (mils)
1	Porter Intersleek	Silicone foul-release coating system	N/A	Open Protected Range: 10-16 5-10 Avg: 12 8
2	E-303B/MIL-P-24441 System No. 21-B-Z	Epoxy zinc-rich primer/epoxy topcoat system	CWGS-09940	Open Protected Range: 14-29 11-18 Avg: 22 14
3	VZ-108d/V-106d System No. 5-C-Z + Devoe ABC#2	Standard vinyl zinc-rich primer and vinyl topcoat with copper ablative antifouling paint	N/A	Open Protected Range: 14-24 7-8 Avg: 19 7
5	VZ-108d/V-766e System No. 5-E-Z	Standard vinyl zinc-rich primer and vinyl topcoat	CWGS-09940	Open Protected Range: 7-15 5-7 Avg: 12 6
extra	85-15 zinc-aluminum System No. 6-Z-A	Standard thermal spray coating	CWGS-05036	Range: 15-40 Avg: 25

extra	System No. 5-C-Z	Standard vinyl zinc-rich primer and vinyl topcoat	CWGS-09940	Open Protected Range: 12-17 5-8 Avg: 13 7

Paint evaluation conclusions and recommendations from CERL were. All of the coating systems performed as expected and provided an adequate degree of corrosion protection for the 6-month test period. Minor differences in performance were noted that would indicate that certain systems would provide better long term protection than others. For example, the relatively brittle epoxy coating system which is typically more prone to mechanical damage caused by ice and floating debris had sustained a significant degree of damage and corrosion along the edges of the gate. The vinyl systems provided improved resistance to damage and edge corrosion. The zinc-aluminum metallizing provided excellent corrosion protection. However, it also exhibited a significant amount of blistering that may impact long term performance. In general, the metallizing and vinyl systems 5-EZ and 5-C-Z should provide excellent long term protection.

10. Self-lubricating Bearings

Five different manufacturers' self lubricating bearings were tested and evaluated at the prototype. The manufacturers and their products were:

Wicket #1
Lubron Bearing Systems, Huntington Beach California
Manganese bronze ASTM B22-C8600 housing with an inner lubricating coating of Teflon PTFE, trade name AQ100.
Wicket #2
Kamatics Corporation (Kaman), Bloomfield, Connecticut
Fiberglass/epoxy housing with an inner lubricating liner (Karon V) of Polyester resin and terafluoethlene.
Wicket #3
Merriman, Hingham , Massachusetts
Lubrite, Bronze Alloy #424, ASTM B22-C86300 (Manganese Bronze). Inner lubricating liner Merriman type G12.
Wicket #4
Thordon Bearing Inc. Burlington Ontario, Canada
Bronze C93200 with inner lubricating liner Thordon trade name (SXL TRAXL)
Wicket #5
Rowend, Liberty Center, Ohio
CDA 8630 (Manganese Bronze) with a inner lubricating material R-8.

Two of the products, Lubron and Thordon were superior in performance with Merriman third Rowend fourth and Kamatics last. The following are photos of each product after testing at the site.

Wicket #1 Bearings
The Lubron bearing showed no wear on either the main hinges of the gate or the prop bearing.

Wicket #2
Kamatics Bearing failed dramatically. The inner lubricating material flaked off the housing of the bearing. The manufacturer stated they made a mistake in the design of the bearing for the test.

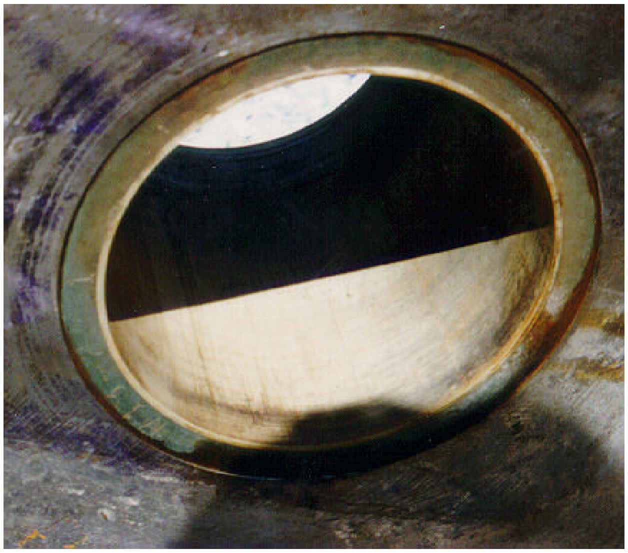
Inside of Kamatics Bearing After Test

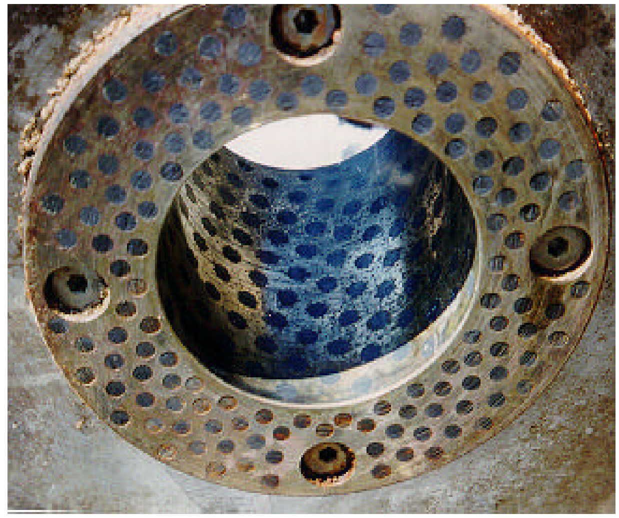
The lubricant material also flaked off the inside of the race of the prop bearing.

Inside Race of Kamatics Bearing
Note lubricant flaked off.

Wicket #4
Merriman Lubrite had begun to loose its inner lubricating surface.

Merriman Lubrite Bearing





Wicket #4
Thordon

The bearings were in good condition.

Wicket #5
The Rowend Bearing experienced sever pitting of the base metal of the bearing caused by galvanic corrosion.

The Olmsted Prototype Hydraulic Operated Wicket Dam has been a valuable tool for testing and evaluating numerous components and materials,. The wickets and cylinders were reinstalled after the evaluation was complete and are now permanently fixed in the raised position. There are no immediate plans to operate the wickets, but the site may be dewatered in the future to reevaluate the long term wear on the components.